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SELECTION OF THE OPTIMAL FORMULATION OF THE BIOPOLYMER SYSTEM FOR THE STIMULATION OF PRODUCTIVE FORMATIONS

The object of study in this paper is the biopolymer system "X" – a complex composition that includes a biopolymer, salts and a thermal stabiliser intended for use in drilling fluids at high temperatures. The components of the formulation include complex reagent "X" for regulating structural, mechanical, rheological and filtration properties, as well as inhibitors (sodium and potassium chloride) and filler. Components of the biopolymer system (sodium chloride, organo-mineral colmatant thermal stabiliser) increase its thermal stability. One of the most problematic areas is the mechanism of sodium chloride's thermal stabilising effect. It is associated with an increase in the overall mineralisation of the drilling mud, which leads to a certain conformation of biopolymer molecules, accelerates gelation processes and counteracts the temperature dilution of the system.

The results obtained can be explained as follows:

– an increase in the concentration of sodium chloride leads to an increase in the ionic strength of the solution, which contributes to a change in the conformation of biopolymer molecules, enhancing intermolecular interactions and, as a result, increasing the viscosity and stability of the system;

– the organo-mineral colmatant heat stabiliser promotes the formation of a filtration crust on the well walls, which prevents fluid loss and reduces rock permeability;

– all components of the system interact with each other, affecting the properties of the solution. The optimum ratio of components allows achieving the required rheological characteristics and ensuring the stability of the system at high temperatures.

As a result of processing the information on technologies for tapping productive horizons, the disadvantages and advantages of each of them were noted. The existing drilling fluid systems used to tap productive horizons at high temperatures were considered. However, more attention was paid to the selection of a new optimal formulation of the biopolymer system, in accordance with the specified rheological and structural and mechanical properties for further implementation in practice. This ensures the possibility of obtaining predictive parameters of the drilling mud.

The proposed system has a number of advantages over similar ones, namely:

– the system retains its properties at high temperatures;

– the system provides the required values of viscosity, filtration and static shear stress;

– due to the use of an optimal formulation, high efficiency is achieved at a relatively low cost.

Keywords: *biopolymer system, drilling mud, colmatant, filtration, well, rheological parameters, regression model.*

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1. Introduction

Improving the quality of work related to the primary opening of productive layers is one of the most important problems of the oil and gas production industry [1].

Research and industrial experience show that development terms, well productivity, and oil and gas recovery rates from formations under the same conditions can be different depending on the quality of work performed during the initial opening of productive formations [2]. At the same time, depending on the filtration properties of reservoir rocks and the physicochemical properties of the fluids that saturate their pores, the use of the same technological operations with the same parameters leads to different final results [3].

The basis of a successful primary opening is the preservation of the natural permeability of the reservoir rocks and the integrity of the well walls in the interval of the productive layer [4]. This can be achieved through the use of such technologies that exclude the possibility of by-products getting into the pores of collector rocks, or such drilling fluids that do not cause a negative effect on the formation in terms of its clogging and loss of stability of the well walls [5].

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Recently, clay-free drilling fluids are increasingly used to open productive horizons, which ensure the highest level of preservation of their reservoir properties [6, 7]. This is largely due to the low content of colloidal particles, the penetration of which into the pore space of the collectors is one of the main factors in the deterioration of their productive characteristics [8]. At the same time, if recently the use of clay-free systems was limited to zones of abnormally low or hydrostatic pressures, now there is an increasing need for their implementation in deep wells with high reservoir pressures and temperatures [9, 10].

Biopolymer system "X" is a clay-free drilling fluid for drilling inclined and horizontal wells, opening of productive horizons in conditions of high pressures and temperatures.

A distinctive feature of the biopolymer system is a high level of mineralization, increased heat resistance and high density, which significantly expands the scope of application of clay-free solutions. At the same time, the biopolymer system preserves all the advantages of biopolymer clay-free drilling fluids and provides a coefficient of restoration of the permeability of collectors, which significantly exceeds similar indicators for traditional weighted solutions.

The aim of research is to ensure effective opening of productive layers under conditions of high temperatures and pressures, while preserving the natural permeability of reservoir rocks and minimizing the risk of complications during further exploitation of the well.

2. Materials and Methods

To prepare the biopolymer system, organic filler K-200 is used, the size of the colmatant particles varies in the range from 200 to 2000 microns, depending on the size of the pores and the collector properties of the formation.

The main advantages of this colmatant are that it is an ecological, natural filler that cannot be dispersed in water. The substance completely dissolves in alkalis, which makes it possible to use it during the primary and secondary opening of productive horizons. Colmatant does not have abrasive properties, does not harm circulation and pumping equipment.

There are also certain limitations in the use of K-200, namely the use of colmatant in the formulation of drilling fluids, which complicates the use of the cleaning system. With a particle size of more than 400 microns, the possibility of using vibrating sieves is completely excluded. During the application of smaller-sized colmatants, it is permissible to use vibrating sieves with an opening of at least 40 mesh. However, in the process of cleaning the drilling fluid from the drilled rock, part of the filler will be separated and discarded, so during work it is necessary to constantly replenish the colmatant to maintain its necessary concentration in the drilling fluid.

Such complications as: absorption of drilling mud, scree and collapse of the walls of the well, cavernous and trough formations, tightening of the drilling tool, gas exposure are also possible. In order to avoid these complications, certain requirements are placed on the brown solution in the interval from 4850 to 4950 m, the parameters should be as follows:

– density 1180–1240 kg/m^3;
– conventional viscosity 35–75 s;
– filtration 5–7 cm^3/30 min;
– SSS 15 – 40/30–100 Pa;
– crust 1 mm;
– sand ≤2 %;
– pH 8–11;
– plastic viscosity 10–25 cP;
– dynamic shear stress of 60–140 dPa.

And in the interval from 4,950 to 5,620 m, the requirements for drilling fluid are more stringent, namely:

– density 1160 kg/m^3;
– conventional viscosity 40–80 s;
– filtration – 6 cm^3/30 min;
– SSS 15 – 40/30–100 Pa;
– crust 1 mm;
– sand ≤1 %;
– pH 8–11;
– plastic viscosity 10–25 cP;
– dynamic shear stress of 90–150 dPa.

In order to choose the optimal formulation of the biopolymer system "X", a number of studies were carried out on the system with the addition of different concentrations of sodium chloride (5, 10, 15, 20, 25 %) and thermal stabilizer colmatant (0.25; 0.5; 0.75; 1; 1.5 %). The change in the parameters of the solution was also studied under the influence of temperature (from 50 to 150 °C) and pressure drop (from 3 to 7 MPa). The results obtained in the course of laboratory tests are shown in the Table 1.

The process of preparing one solution was as follows (Fig. 1): a certain percentage of sodium chloride is added to 0.5 l of biopolymer system "X" and mixed for 25–40 min.

Table 1

Results of the experiment for the study of clay-free biopolymer system "X"

Experiment	Properties of drilling fluid					
	ρ, kg/m^3	*T*, s	$\Phi_{BM\text{-}6}$, cm^3/30 min	Φ_{HTHP}, ml/30 min	$SSS_{10/1/10}$, dPa	$SSS_{10/1/10}$ at 80 °C, dPa
1	1210	69.6	4.0	15	43.1/46.9/51.2	30.2/30.6/36.4
2	1210	58	4.0	12	43.1/44.0/49.3	21.5/22.0/29.2
3	1180	65.2	3.5	7	39.3/40.2/43.6	24.9/25.9/30.6
4	1160	89.2	3.7	14	46.9/55.5/59.4	35.0/35.4/37.8
5	1170	67.6	3.5	13	39.7/42.6/46.4	28.2/30.6/35.9
6	1200	110.4	3.0	12	50.3/60.8/60.3	36.4/38.8/44.0
7	1190	112.8	3.5	5	57.0/58.4/64.2	35.9/42.6/46.9
8	1220	78	3.5	8	46.4/50.8/55.5	31.6/32.6/40.7
9	1220	130	2.5	9	60.8/64.6/69.4	39.3/44.0/46.4
10	1210	152.8	2.5	8	55.5/61.8/66.6	23.9/31.1/33.0
11	1240	70.4	3.0	9	45.0/49.3/55.1	30.6/35.4/37.8
12	1170	125.6	3.0	7	32.1/35.9/38.8	11.5/14.8/24.9
13	1200	67.6	3.5	16	38.8/46.9/50.3	30.6/33.0/35.4
14	1160	88.4	3.5	11	27.8/32.1/37.8	22.0/23.9/25.9
15	1150	76.8	3.5	14	55.1/58.4/63.7	43.0/45.5/48.8
16	1180	86.6	3.7	9	47.9/50.3/53.6	29.7/30.6/32.6
17	1260	106.8	3.0	8	52.2/54.6/58.4	31.1/33.0/37.3
18	1200	76.4	3.5	9	46.4/48.4/53.6	28.2/29.2/33.0
19	1250	93.2	3.0	21	53.1/55.5/58.9	34.0/36.9/43.6
20	1230	66.4	3.5	11	46.9/48.8/53.1	29.7/31.6/33.0
21	1240	99.2	3.0	7	29.2/32.1/35.4	11.0/12.4/17.7
22	1160	89.2	3.5	9.5	50.8/53.6/57.5	30.6/35.4/39.3
23	1170	104.4	4.0	9.5	53.1/57.0/61.3	38.3/40.2/44.0
24	1170	99.2	3.5	9	27.3/31.1/35.4	11.5/14.4/18.2
25	1170	138.8	3.0	17	61.3/63.7/68.5	40.7/45.0/49.8

Fig. 1. The process of preparing a biopolymer system

After that, a heat stabilizer was added and stirred for about 1 hour. Thus, the process of preparing one drilling fluid took approximately 1.5 hours.

3. Results and Discussion

Regression models in the form of second-order polynomials were used to process the measurement results.

The main indicator for choosing the optimal concentration of the biopolymer system is filtration.

According to the condition, the most adequate regression model for the filtering indicator corresponds to a certain combination of basic functions. The calculated values of the filtration index $\hat{\Phi}$ according to this model are given in the Table 1. It is worth noting that within the scope of planning the experiment, the most adequate model is linear with respect to the pressure drop Δp on the filter crust and does not take into account the influence of Δp on other variable factors.

The assessment of the adequacy of the adopted regression model can be performed on the basis of the results of testing a set of static hypotheses about the characteristic distribution of the residuals $\Delta_i = \hat{\Phi}(T_i, c_{ci}, c_{ai}, \Delta p_i) - \Phi_i$, namely, about their centering H_0: $M\{\Delta\} = 0$ and uncorrelation $H_0 : \rho_{\Delta x} = 0$, where M is the symbol of mathematical expectation, $\rho_{\Delta x}$ is the correlation coefficient between Δ and variable factors $x = \{T, c_c, c_a, \Delta p\}$.

Before choosing the optimal recipe, it is possible to pay attention to how the filtration index is affected by the change in the concentrations of sodium chloride and colmatant of the thermal stabilizer at different temperatures and pressure drops, Fig. 2–4.

With the help of the "MudExpert" expert system and the "Experimenter" program, the optimal formulation of the biopolymer system for the given mining-geological conditions was selected, which corresponded to the following composition: sodium chloride 9 %, organo-mineral colmatant thermal stabilizer 0.375 %.

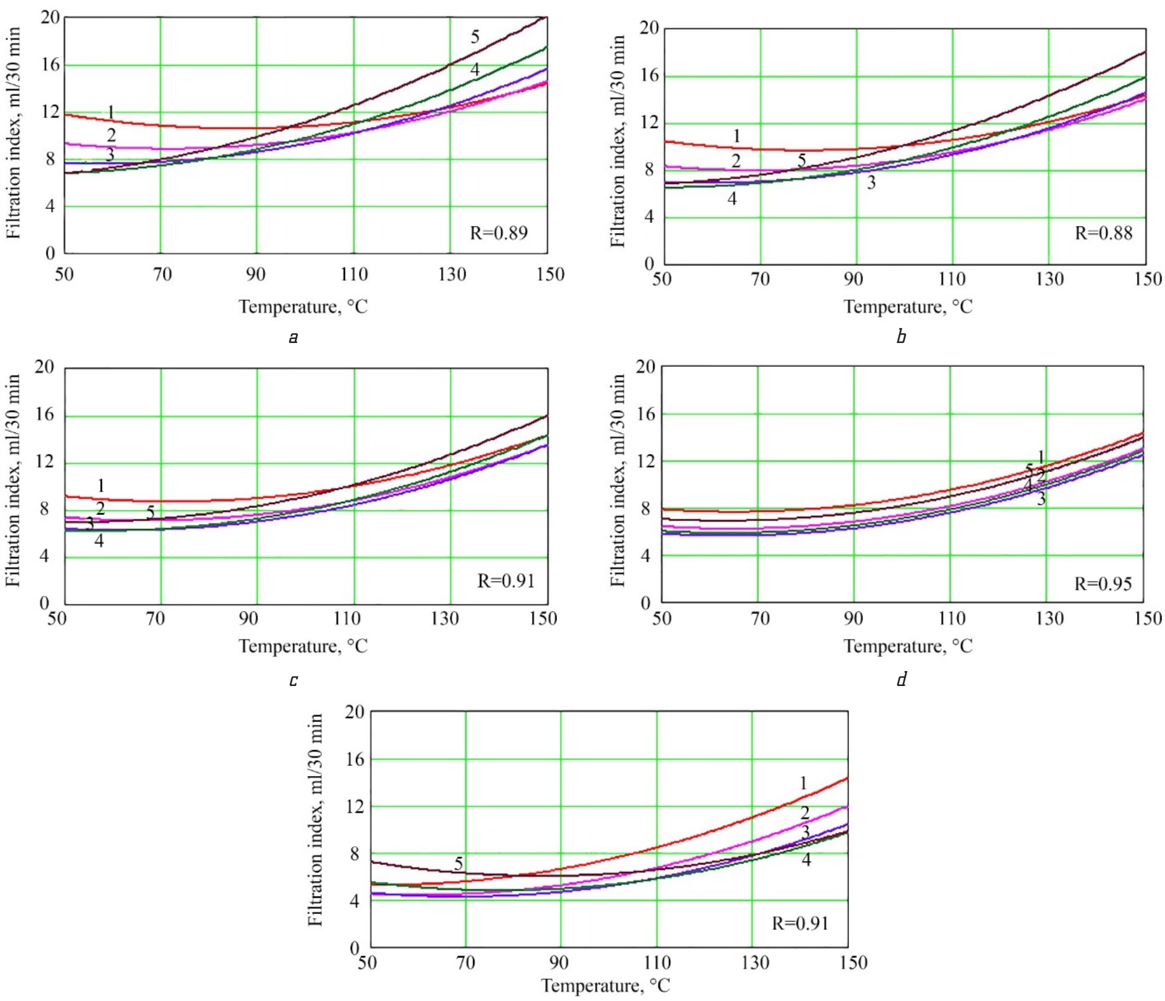

Fig. 2. Influence of sodium chloride concentrations (1 – c_c=5 %, 2 – c_c=10 %, 3 – c_c=15 %, 4 – c_c=20 %, 5 – c_c=25 %), colmatant stabilizer (c_a: *a* – 0.25 %, *b* – 0.5 %, *c* – 0.75 %, *d* – 1.0 %, *e* – 1.5 %) and pressure drop (Δp=3 MPa) on the dependence of the filtration index of the biopolymer system "X" on temperature

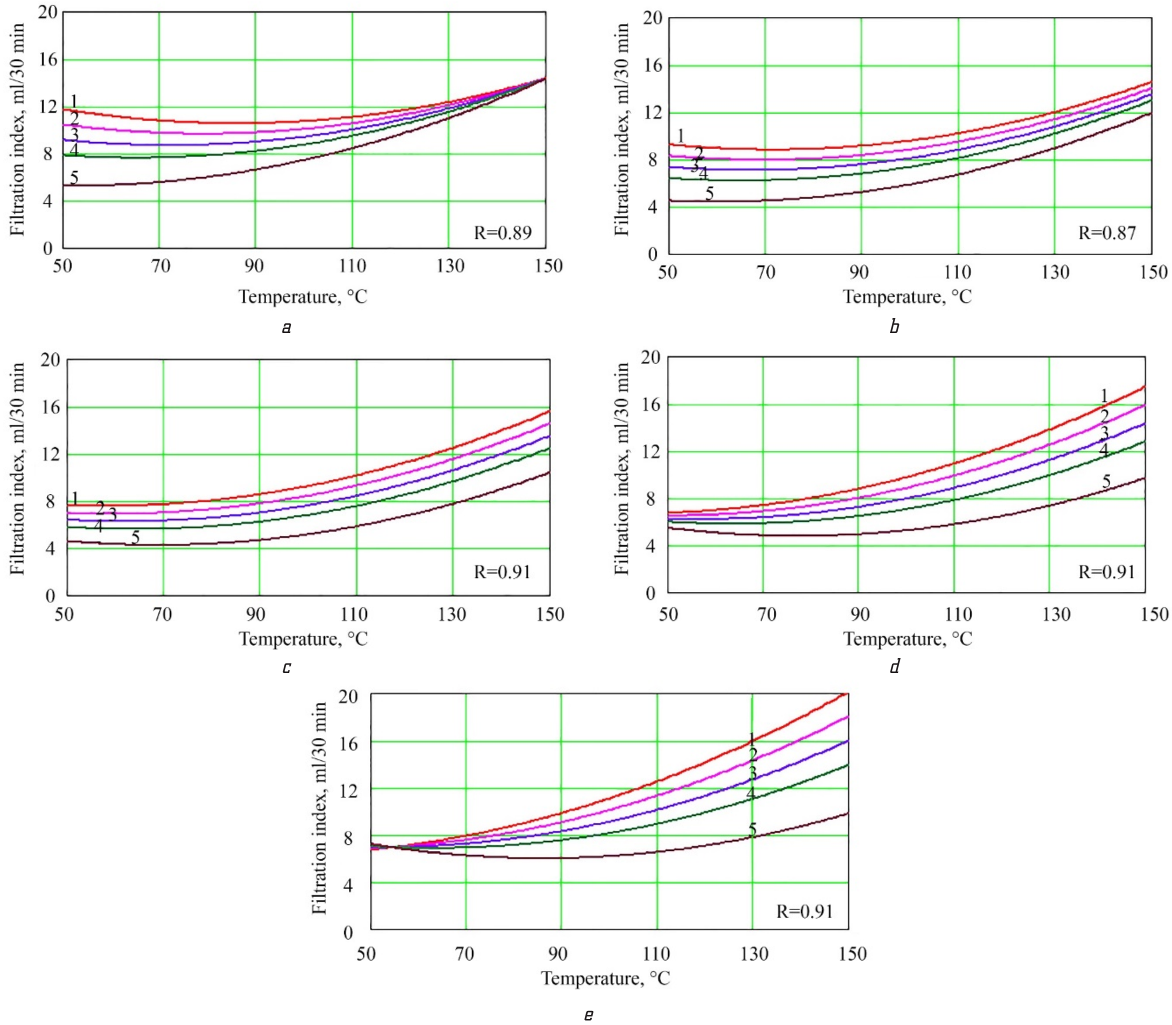

Fig. 3. The influence of the concentrations of colmatant stabilizer (1 – c_a=0.25 %, 2 – c_a=0.5 %, 3 – c_a=0.75 %, 4 – c_a=1.0 %, 5 – c_a=1.5 %), sodium chloride (c_c: *a* – 5 %, *b* – 10 %, *c* – 15 %, *d* – 20 %, *e* – 25 %) and pressure drop (Δp=3 MPa) on the dependence of the filtration index of biopolymer system "X" on temperature

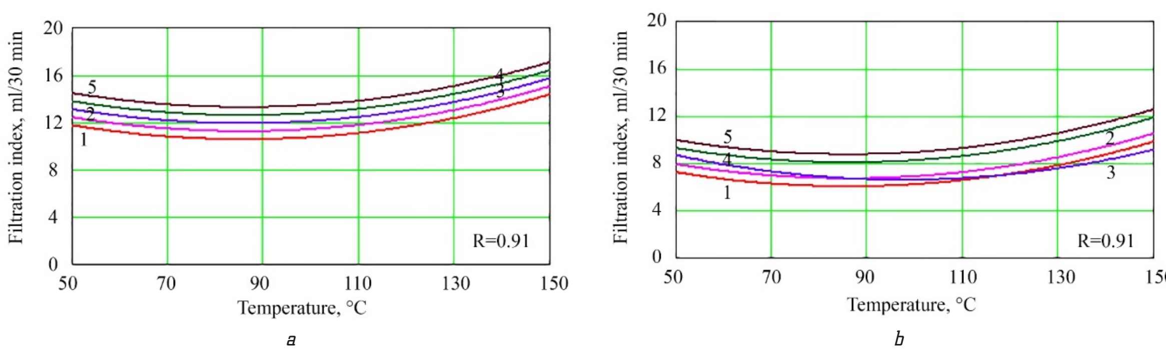

Fig. 4. Influence of the concentrations of colmatant stabilizer (*a* – c_a=0.25 %, *b* – c_a=1.5 %), sodium chloride (*a* – c_c=5 %, *b* – c_c=25 %) and pressure drop (1 – Δp=3 MPa, 2 – Δp=4 MPa, 3 – Δp=5 MPa, 4 – Δp=6 MPa, 5 – Δp=7 MPa) on the dependence of the filtration index of the biopolymer system "X" on temperature

The obtained values of the correlation coefficients on the graphs indicate the relationship of the studied parameters and the adequacy of the obtained research results.

Forecast parameters of the drilling fluid for this formulation:

– density – 1170 kg/m^3;
– conventional viscosity – 70 s;
– filtration – 3.6 cm^3/30 min;
– SSS 1/10 – 44/49 Pa.

Predicted values of static shear stress and rheological parameters in the temperature range from 20 °C (temperature at the mouth) to 136 °C (temperature at the bottom of the well) of the selected formulation of biopolymer system "X" are given in Table 2.

As a result of the processing of information on the technologies of opening productive horizons, the disadvantages and advantages of each of them were indicated. Already existing systems of drilling fluids, which are used to open productive horizons in conditions of high temperatures, are considered.

Table 2

Predicted values of rheological and structural-mechanical properties for optimal formulation

Temperature, °C	Rheological parameters			Static shear stress		
	τ_0, Pa	k, Pa·s^n	N	Θ_{10s}, Pa	θ_1, Pa	θ_{10}, Pa
20	7.904	2.081	0.609	3.2	3.2	3.9
30	6.642	1.959	0.575	2.9	2.9	3.5
40	5.501	1.832	0.547	2.5	2.5	3.0
50	4.479	1.701	0.526	2.2	2.2	2.6
60	3.577	1.565	0.511	1.9	1.9	2.3
70	2.796	1.425	0.503	1.7	1.7	1.9
80	2.134	1.281	0.501	1.4	1.4	1.6
90	1.593	1.132	0.507	1.2	1.2	1.3
100	1.171	0.978	0.518	1.0	1.0	1.1
110	0.869	0.821	0.536	0.8	0.8	0.9
120	0.869	0.659	0.561	0.7	0.7	0.7
130	0.626	0.492	0.592	0.6	0.6	0.5
136	0.647	0.390	0.614	0.4	0.4	0.5

Research aimed at the development and optimization of the biopolymer system "X" has significant practical significance for the oil and gas industry. The obtained results make it possible to increase the efficiency of the opening of productive layers, expand the possibilities of drilling in difficult geological conditions and reduce the negative impact on the environment.

Despite the significant value of the conducted research, there are certain limitations that should be taken into account when interpreting the results. The obtained results were obtained in laboratory conditions, which may differ from real drilling conditions. The study was conducted in a limited range of temperatures, pressures and concentrations of components. It is necessary to conduct longer field tests to confirm the effectiveness of the system in real conditions.

Martial law also had an impact on the results of the research, because the difficulty lies in importing the necessary equipment and reagents.

In the perspective of further research, it would be desirable to pay attention to the study of the influence of other factors on the properties of the system, the search for the optimal ratio of components for different geological conditions.

4. Conclusions

In the course of the study, it was shown that the biopolymer system "X" demonstrates high stability of its properties in the entire range of investigated temperatures. This testifies to its ability to work effectively in difficult temperature conditions of the well.

The selected recipe provides an optimal ratio between viscosity, plasticity and static shear stress, which is necessary for the effective opening of productive horizons and prevention of complications during drilling.

Predicted values of the parameters indicate that the biopolymer system "X" will provide the necessary properties of the drilling fluid for the effective opening of productive horizons in the specified depth interval in the following composition: sodium chloride 9 %, organo-mineral colmatant thermal stabilizer 0.375 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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